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CarbEF: a software for reporting carbon emissions from deforestation and forest degradation under REDD+

Applying IPCC guidelines on forest cover change maps

Astrid Verhegghen
Bruno Combal
Hugh Eva
With the contribution of Catherine Bodart and Amélie Arquero

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Contact information

Name: Frédéric Achard
Address: TP261, JRC, Ispra, Italy
E-mail: frederic.achard@ec.europa.eu
Tel.: +390332785545

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Abstract

This document describes a carbon emission reporting method based on maps of forest changes. The method is based on the Intergovermental Panel on Climate Changes (IPCC) guidelines to define forests, deforestation, and forest degradation from multi-temporal tree cover change maps. The CarbEF module of the IMPACT toolbox software implements this method and produces reports.

CarbEF module reports “activity” data and carbon emissions from deforestation and forest degradation using:

(i) A map of tree cover loss, usually generated from multi-temporal tree cover maps at fine spatial resolution (i.e. maps of tree cover loss at ≤30m resolution),

(ii) A national forest definition and

(iii) Forest carbon stock values (from national data or other scientific literature).

CarbEF can be used to analyse a single period of change or to compare two consecutive periods.

Acronyms and definitions used in CarbEF

Activity data	Changes in forest area over a period of time. These values are derived from maps of forest cover changes.
Deforestation (definition used in CarbEF)	Transition from Forest cover to non-Forest Cover within a Minimum Forest Unit (MFU). Non-Forest cover is assigned when the tree cover percentage falls below a selected threshold (typically 30%).
Forest Degradation (definition used in CarbEF)	Reduction of forest cover percentage within a MFU remaining Forest. The tree cover percentage within the MFU remains higher than a selected threshold (typically 30%).
Forest carbon stock	The carbon content of a forest per unit area at the beginning of the analysis
Emission factor	The quantity of CO_2 per unit area that is lost during a conversion from forest to non-forest or from forest to degraded forest. The emission factor is multiplied by the activity data to produce estimates of carbon emissions.
IMPACT Tool	Software developed by the JRC which offers a combination of remote sensing, photo interpretation and processing technologies in a portable and stand-alone GIS environment. CarbEF is implemented as a module in the IMPACT Tool.
MFU	Minimum Forest Unit. A MFU is defined as a regular shape (e.g. square) and size, typically 0.5 or 1 ha, to allow one to apply classification rules to define forest areas, deforestation and forest degradation from multi temporal maps of tree cover.
ND	No data
NT	No Trees (the pixel is characterised by the absence of trees)
NT-NT	No Trees to No Trees (the pixel is characterised by the absence of trees over the period)
Period	The module allows the user to compute forest changes and emissions from either one or two periods – these are input as integral year ranges.
T	Trees (the pixel is covered by trees)
T-NT1	Trees to No Trees during period 1
T-NT2	Trees to No Trees during the period 2
T-T	Trees to Trees

	(the pixel is covered by trees over the period)

1 Introduction – Reporting Carbon Emissions for REDD+

The United Nations Framework Convention on Climate Change (UNFCCC) encourages countries to submit a Forest Emission Reference Level (FREL) as a benchmark for assessing each country performance in implementing REDD+ activities. After submitting their FREL, countries are requested to report on carbon emissions every two years through Biennial Update Reports (FAO, 2015).

In this context, the CarbEF module offers to REDD+ countries the mean to use maps of tree cover loss to report on carbon emissions from forest cover changes. CarbEF creates an activity data map and computes deforested and degraded areas and their associated emissions. An IPCC compliant (IPCC, 2006) definition of forest degradation and deforestation is defined according to the forest definition selected at national level.

The national forest definition is based on selected thresholds for:

- Minimum crown cover (expressed in percentage);
- Minimum tree height (expressed in metres);
- Minimum area (expressed in hectares).

The minimum crown cover and minimum area thresholds can have a strong impact on the estimates of deforested or degraded areas and their related carbon emissions. Changing the crown cover from 30% to 10% can result in a significant difference in the estimate of carbon emissions (Figure 1 A). According to the minimum area threshold selected, the same amount of tree canopies loss will cause the area to be considered as a forest loss or not (Figure 1 B). A more detailed description of this issue can be found in the technical document entitled "Technical considerations for Forest Reference Emission Level and / or Forest Reference Level construction for REDD+ under the UNFCCC" (FAO, 2015).

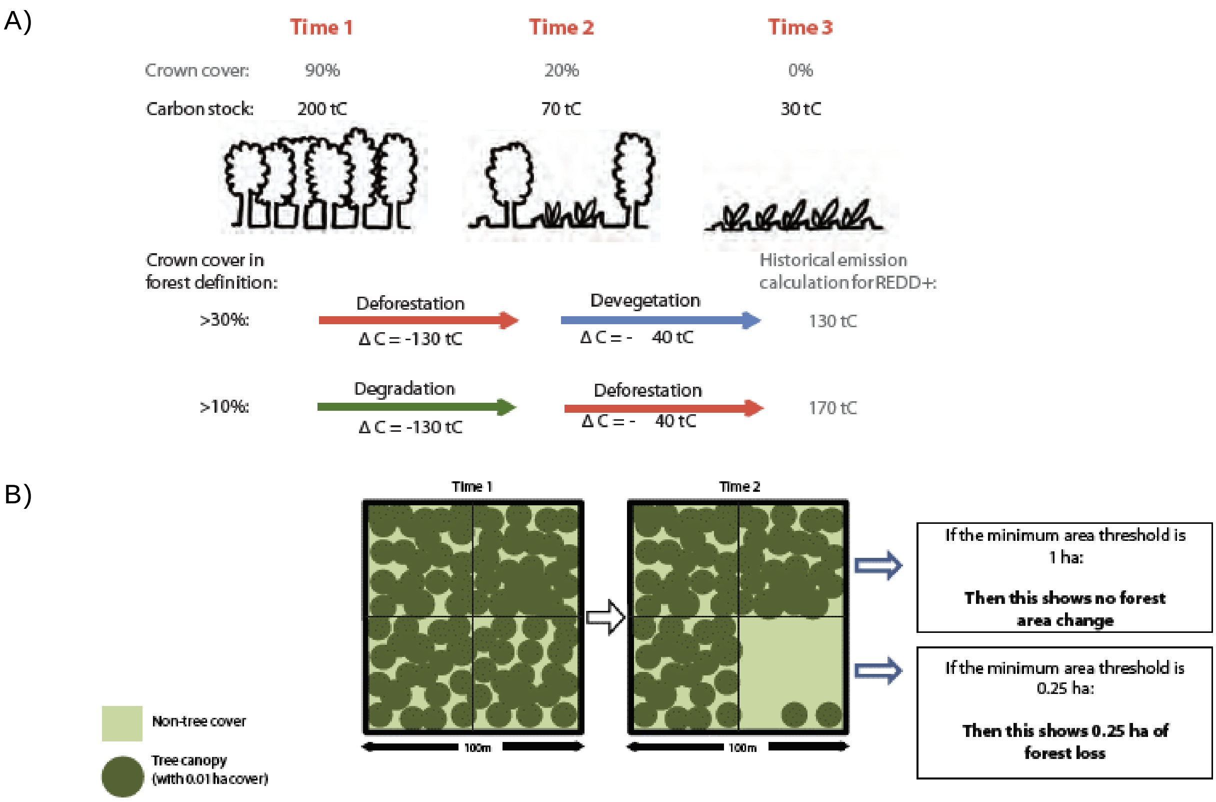


Figure 1 : Consequence of different forest definition minimum cover and minimum area thresholds on estimates of deforestation and forest degradation. (A) is modified from Walker et al, 2013 in FAO, 2015 (B) comes from FAO, 2015.

2 Concept and datasets used in CarbEF

2.1 General concept

For any region where a high resolution map of tree cover loss and estimation of carbon stock is available, CarbEF reports forest change (deforestation and forest degradation) areas and its associated carbon emissions.

A first and straightforward application is the analysis of a single period of change. The period can cover one or several years of tree cover loss.

A second application is the comparison of two periods of change. The module is designed to analyse tree cover loss occurring in two consecutive period in a consistent way. It can therefore report for information about the sequence of loss, for example degradation in the first period followed by deforestation in the second.

In both cases, two parameters (fitting the national forest definition) are set by the user to define the forest areas:

- The cell size of a regular grid (called Minimum Forest Unit - MFU). For compliance with IPCC guidelines, the MFU needs to be as close as possible to the minimum area used in the national forest definition;
- The minimum tree cover percentage within a MFU. This threshold is used to define forest cells within the systematic grid. For compliance with IPCC guidelines, the tree cover percentage needs to be as close as possible to the minimum crown cover used in the national forest definition.

The third parameter of the forest definition, the tree height threshold is not included as a parameter in the CarbEF module. Currently, regional datasets inferring tree height change over time are not available.

Forest cover and forest cover change maps are frequently derived from satellite imagery. Remote sensing actually provides information on the presence (or absence) of tree canopy within pixels, which can be mapped or reported at different dates either as a continuous parameter (e.g. percentage of tree cover) or as a binary class (e.g. tree cover versus non tree cover). The tree cover loss is usually provided as a binary information (loss / no loss of tree cover). In case of a continuous parameter such as percentage of tree cover for fine spatial resolution maps (e.g. pixels < 0.1 ha), the tree cover loss is usually defined as the full disappearance of tree cover.

In CarbEF, the tree cover loss map used as input is labelled into three main classes at the pixel level: (i) presence of tree canopy during the period, (ii) absence of tree canopy during the period and (ii) loss of tree canopy during the period. The count of pixels with “presence of tree canopy” in a MFU is used to define the forest or non-forest status from a given proportion threshold.

CarbEF aims at working with tree cover loss maps available at fine spatial resolution (i.e. ≤ 30m resolution). Users can either upload their own maps of tree cover change (at local or national level) or use available maps from external sources (e.g. at regional or global scales) such as the Global Forest Change maps (https://earthenginepartners.appspot.com/science-2013-global-forest) or the JRC Roadless product (Vantcutsem and Achard, 2017; Vantcutsem et al, in preparation).The user has to reclassify the selected tree cover change map to the classes compliant with CarbEF (see section 2.2).

The analysis of the tree cover loss map is done inside the grid of MFUs. A forest change map differentiating deforestation from degradation is derived. This “activity map” is then combined with Emission Factors to report carbon emissions. Emissions Factors quantify emissions per unit for each “activity” (IPCC 2006): deforestation or degradation in this case.

CarbEF can use two types of input to produce the emission factors: (i) either a single value of carbon stock for the area of interest. The value corresponds to the average carbon loss for a conversion of forest to non-forest area (derived from the scientific literature or local inventories) or (ii) a spatial map of biomass (expressed in carbon content).

The unit input values in CarbEF is in tons of carbon per hectare (tC/ha). CarbEF reports emissions values in tons of Carbon Dioxide equivalent per year (t. eq. $C0_2$/y), to be compliant with UNFCCC Parties decisions (UNFCC, Decision 12/CP.17, par.7).

In the current version of CarbEF, changes leading to a carbon gain such as forest regrowth are not considered.

Two optional cartographic inputs (when available) can be imported and used in CarbEF:

- A land use layer;
- An exclusion map.

The inclusion of a land use layer allows CarbEF to report carbon emission estimates for different land use classes (e.g. emissions from logging concession, protected areas, in relation to proximity to roads …). This way, the user can disregard estimations of deforestation or degradation belonging to a certain land use category (e.g. plantations).

The exclusion map allows identifying areas affected by significant disturbance that are not necessarily deforestation (e.g. fires).

The different input datasets and definitions used in CarbEF are detailed hereafter.

2.2 Tree cover loss maps

The creation of the “Tree cover loss” map is not the purpose of CarbEF, the user has to create it or use existing products mentioned in section 2.1. and 5.2. The user has then to reclassify the map into specific classes. Table 1 summarises the possible values and corresponding events. In the case of two periods, the five classes of Table 1 are expected. If the module is run on a single period, only the code 3 should be assigned to tree cover loss.

We consider “Tree” (T) pixels, corresponding to locations where tree canopies have been detected. This detection is generally done by monitoring the spectral properties of each pixel of the region, using satellite time series (typically Landsat or Sentinel-2). The same time series allow detecting changes, changing (T) pixel into non-tree (NT) pixel, corresponding to case where the tree canopies removal brought the pixel spectral signature below tree material detection. The removal of tree material can happened in any of the two predefined periods of time. The overall information, at pixel level, is summarised in a single map, reporting for pixel that remained trees for the two periods of time (T-T), those that were not trees from the beginning of the observation (NT-NT), and those that were converted from T to NT in the first or the second period (T-NT1 and T-NT2). In the current version, regrowth are not considered, therefore NT in the first period can only be followed by NT in the second.

The tree cover loss map must be in an equal area projection, with unit in metres, to allow summing up pixels areas. The other inputs (see their description further down) are reprojected to the same projection as the input tree cover loss map, and resampled to the same pixel resolution, with a pixel grid matching the input tree cover loss map.

In the case of two periods, consistent data must be available to ensure the validity of the comparison. Section 5.3 shows that the use of historical data from the Landsat sensor needs to be carefully assessed, due to changes in the number of scenes available at different epochs.

Table 1: classes of the "Tree cover loss" map indicating tree presence, absence and loss for two periods

Data encoding	Class name	Interpretation	Colour	RGB code
0	ND	No data		0,0,0
1	T-T	Trees are present in the pixel for the 2 periods		38,105,0
2	NT-NT	No tree canopy presence observed in either period		255,255,255
3	T-NT1	The trees present in the pixel were lost during period 1		255,255,0
4	T-NT2	The trees present in the pixel were lost during period 2		230,0,0

2.3 Definition of the Minimum Forest Unit

To convert a tree cover loss map to a forest map, CarbEF defines units of forest according to a country forest definition. The forest units are created based on the cell size defined by the user according to the minimum area of the forest definition.

CarbEF creates a grid of MFUs across the tree cover loss map used in input (Figure 2). A MFU unit is classified as forest according if its percentage of (T) pixels is beyond the threshold defined by the user.

The inputs and the outputs of the CarbEF module have therefore different minimum mapping units (MMU). The MMU of the input files corresponds to the size of the pixel of the tree cover loss map. The MMU of the output files is equal to the MFU size. Figure 4 give a practical illustration of the transformation of the input image at a Landsat resolution, into a raster map with the resolution of an MFU.

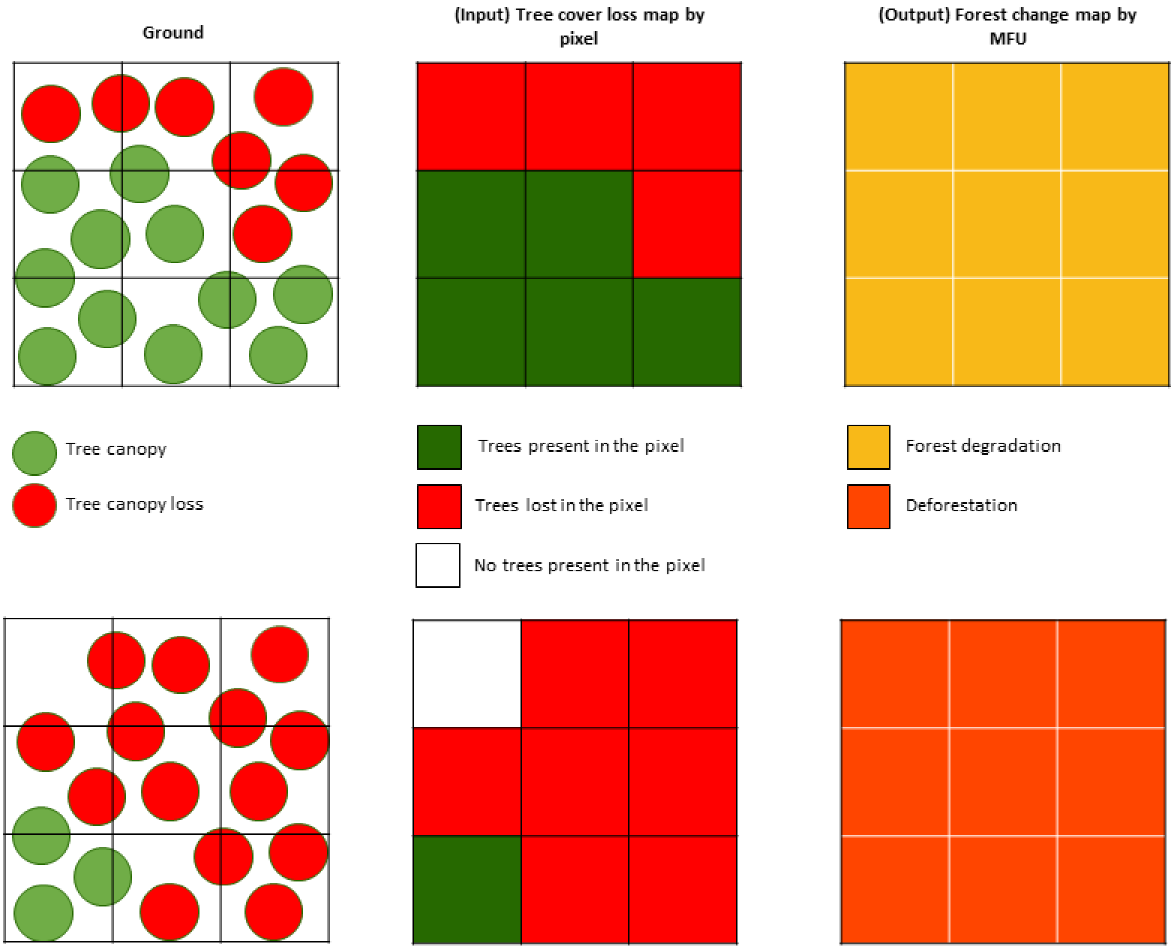


Figure 2 : Resolution of the input and output maps of CarbEF and classification of the Minimum Forest Unit (MFU). The color scheme correspond to a tree cover loss in period 2

The grid is anchored to the upper left corner of the map, and has a horizontal and vertical step as defined in the software interface, counting in pixels of the map. The choice of the dimensions of the MFU is therefore controlled by:

- The typical area of the minimum area of the forest definition, as defined by each country (typically 0.5 ha or 1 ha);
- The tree cover loss map pixel size.

For example, with a tree change map based on Landsat imagery, pixels have a size of 30 m x 30 m. Using a grid cell size of 3 x 3 pixels corresponds to an MFU of 9 x 900 m^2, or 0.81ha. A grid cell size of 4 x 4 pixels would correspond to an MFU size of 1.16 ha. A typical size of 1 ha for a MFU is therefore underestimated by a 3 x 3 pixels cell grid and overestimated by a 4 x 4 pixel grid.

The MFU are used in CarbEF to define the local state of the forest and to do the distinction between what is “degraded” or “deforested” by counting the proportion of pixels that correspond (T-NT1 or T-NT2) or not (T-T) to a tree loss.

When one or several (T) pixels are lost inside a MFU, the term **forest degradation** applies if the remaining percentage of tree cover is above the threshold of the minimum percentage required by the forest definition, and the term **deforestation** applies if the tree cover is brought below this percentage.

Therefore, the proportion of the MFU surface represented by a pixel depends on the grid cell size and the tree change map pixel size. Here are some examples:

30 m x 30 m Imagery (typically Landsat):

Grid of MFU: 3 x 3 pixels represents 0.81 ha, 1 pixel represents 11 % of the MFU area

Grid of MFU: 4 x 4 pixels represent 1.44 ha, 1 pixel represents 6 % of the MFU area

20 m x 20 m imagery (typically Sentinel 2 or Spot):

Grid of MFU: 4 x 4 pixels represents 0.64 ha, 1 pixel represents 6 % of the MFU area

Grid of MFU: 5 x 5 pixels represents 1 ha, 1 pixel represents 4 % of the MFU area

10m x 10m (typically Sentinel 2):

Grid of MFU: 7 x 7 pixels represents 0.49 ha, 1 pixel represents 2 % of the MFU area

Grid of MFU: 10 x 10 pixels represents 1 ha, 1 pixel represents 1 % of the MFU area

The 3 x 3 pixels grid is considered an absolute minimum to perform the computation, as each pixel represents 11% of the MFU area: a coarser representation (e.g. with a 2 x 2 grid cell) would forbid taking any reliable decision on the basis of the proportion of pixel within the MFU.

For a 3x3 pixels grid, it is suggested to leave the tree cover threshold as 30% (which is the software default setting).

2.4 Forest carbon stock

CO_2 emissions are estimated by converting the areas of deforestation or degradation by their corresponding amount of carbon (forest carbon stock). The unit of the input carbon stock is in tons of carbon per hectares (tC/ha). The output is converted in tons of Carbon Dioxide equivalent per year (t. eq. CO_2/y) assuming that 1 ton of Carbon equals 0.2727 ton of CO_2.

Two approaches are considered:

1) Constant value of forest carbon stock for the whole studied area

A single value is given for the whole area processed. If different areas have different carbon stock values, they need to be processed separately.

2) Map of forest carbon stock.

The map of carbon stock can be a stratified map (different values per strata) or a map with a value of biomass for each pixel. The user is free to define this map, the only constraint being to have pixels with values in tC/ha. The software will reproject the map and resample its pixel size to map the tree cover loss map.

The corresponding Emission Factor for Deforestation and Forest Degradation is calculated during the analysis at the scale of the MFU. As described in section 3.3, two different options are offered to the user for calculating the emissions, taking either the entire forest carbon stock of the MFU (option A) or the carbon stock of the pixels corresponding to a tree-presence loss (option B). For option A, the user can assign a proportion of the total forest carbon stock that will be considered for emissions estimation in case of forest degradation. The percentage (0% to 100%) of the total forest carbon stock can be assigned, according to the expert knowledge. By default, the proportion is set to 30 %. In case of deforestation, the whole amount (100%) of carbon content will be considered for the emissions estimates.

2.5 Land use layers

The activity data and the emissions calculated by the module can be disaggregated against different categories of land use. By land use, we mean different affectations of the forest domain (logging concessions, protected areas, etc.): the output lists the different land use, their corresponding areas and their contribution to the total emission per period.

The land use is represented with a shapefile, made of non-intersecting polygons: this means that a pixel of the activity map is attributed to only 1 class of landuse. If needed, the software reprojects this layer to the same projection as the input layer.

When creating this vector layer, a field is required with an identifier indicating to which landuse each polygon belongs to. This class identifier can be either a string (it is better to avoid using accents and special characters) or a number. When choosing this vector file from CarbEF interface, the user will be able to choose the appropriate field to allow Carbef to allocate to each class of landuse its contribution to the emissions.

2.6 Exclusion

The module offers the possibility of using a raster map (called "exclusion map") identifying zones that should not be taken into account in the computation of the emissions from deforestation and degradation.

Separation between tree cover losses caused by natural or anthropogenic factors is not really feasible with remote sensing data. Some natural or anthropogenic changes may have nearly identical spectral signatures at pixel level (GFOI, 2016). They must be distinguished by additional information. As a result, the tree loss cover map could include forest loss not due to anthropogenic activities or perturbation that did not result into the emission of the biomass

Let's consider three examples:

- If a fire occurred in a large area and only the understorey is burnt, the satellite image classification identifies those pixels as changed pixels, but the trees are still standing: the vast majority of the available carbon content was not released. In this case, one want to decide how to report about the carbon loss separately;
- Changes observed along riverbeds due to river shifts or water level changes can result in false positive detection of trees loss;
- Windblown trees: the trees are detected as a loss but the cause is not anthropogenic

More cases can be identified and correspond to the expert's knowledge of the local landscape and practices.

CarbEF allows masking out regions for which the tree loss detected should not be accounted in the anthropogenic carbon emission and would deserved a separated processing.

In these cases, the user can flag those pixels in the so-called exclusion map. CarbEF will not add the contribution of those pixels to the grand total of emissions, but will separately list their total areas, and the amount of carbon that is available for those pixels: the user decides then how to handle the specific cases.

The flag codes in the exclusion map are:

0: Not an exclusion case. The corresponding pixel in the tree change map is processed as usual and its contribution is added to the emissions grand totals

1..N: A code identifying a class of pixel to treat apart. Use as many class codes as you need to separate the different cases.

3 Methodology

In this section, the methodology is presented for two periods, as it is a more complex case. In the case of an analysis over a single period, anything related to the period 2 can be ignored.

3.1 General workflow

The inputs and outputs of the CarbEF module are illustrated in Figure 3.

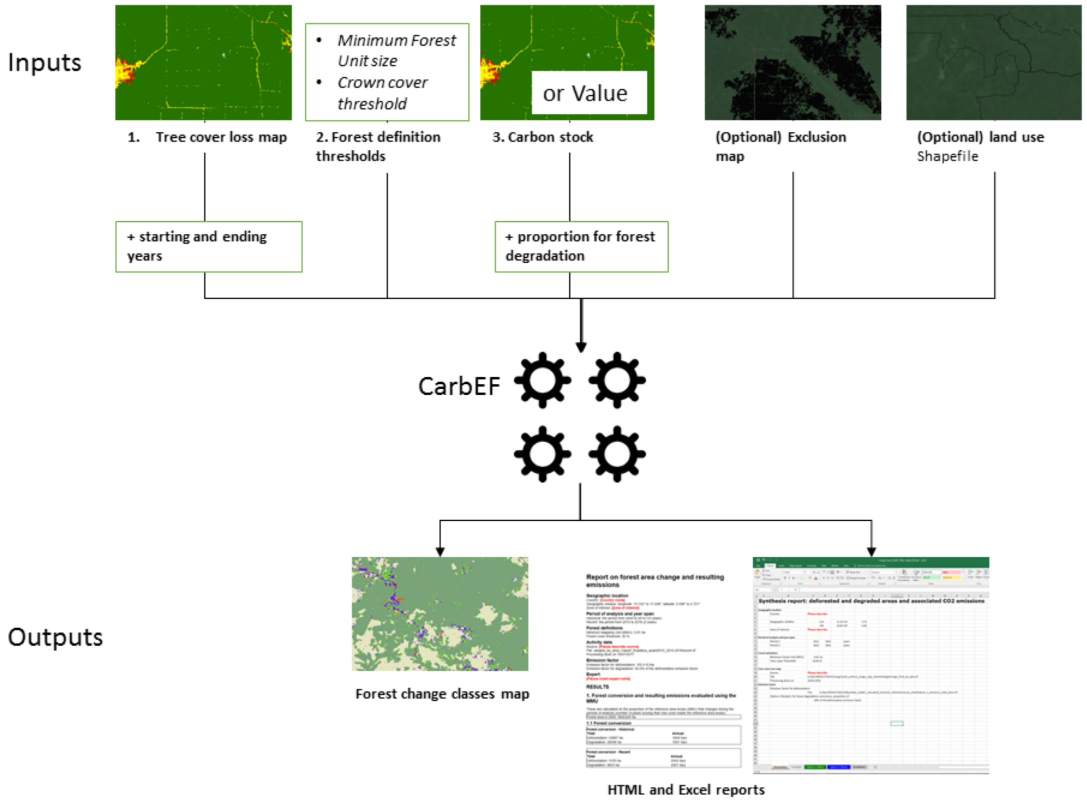


Figure 3: Inputs and outputs of the CarbEF Module (processing icon by Freepik from www.flaticon.com, licensed by Creative Commons BY 3.0 CC 3.0 BY)

The CarbEF has three mandatory inputs:

1. A tree cover loss map

Together with the tree cover loss map, the starting and ending years of the periods of the change map needs to be defined (by default 1 periods, can be run with 2);

2. The threshold values of the forest definition

- the minimum area as the MFU size in pixels;
- the tree cover threshold in percentage;

3. The forest carbon stock, as a constant or as a map

If a map is used, the software reprojects it to the tree cover loss map projection, and resamples it to the same spatial resolution.

CarbEF supports two accounting methods, named option A and option B, and reports for both of them. In option A, the areas and emissions are calculated according to the entire tree cover content of the deforested or degraded MFU. In option B, only the pixels detected as tree cover loss in deforested or degraded MFUs are taken into account in the areas and emissions estimates.

For option A, the proportion of the emission due to degradation can be expressed as a percentage of the carbon stock (either if defined as a constant or as a map).

The other mandatory inputs shown in the interface are only used to manage the output files creations (filename, overwriting and report language).

The algorithm can also use the following optional parameters:

- A land use layer (see section Land use layers);
- An exception map (see section Exclusion).

CarbEF creates the following outputs:

- A map of forest change;
- An html and Microsoft ® Office Excel report making the synthesis of the processing, in French and English.

The next sections describe the methodology of the computation and the outputs.

3.2 Minimum Forest Unit change classes

3.2.1 Forest change map

A forest change map is created based on the input map of tree cover loss and according to decision rules detailed in the next section. The spatial resolution of the output raster corresponds to the MFU width. The MFUs are classified into thirteen classes based on the count of pixels with tree-presence, tree-absence or loss of tree-presence in each unit. The classes can be grouped in four main classes, forest (10), deforestation (classes 21, 22, 23 and 24), forest degradation(classes 31, 32 and 33) and non forest (41, 42, 43 and 44). Figure 4 presents an illustration of the input and output maps. A detailed description of the MFUs classes is available in Table 2 (see below).

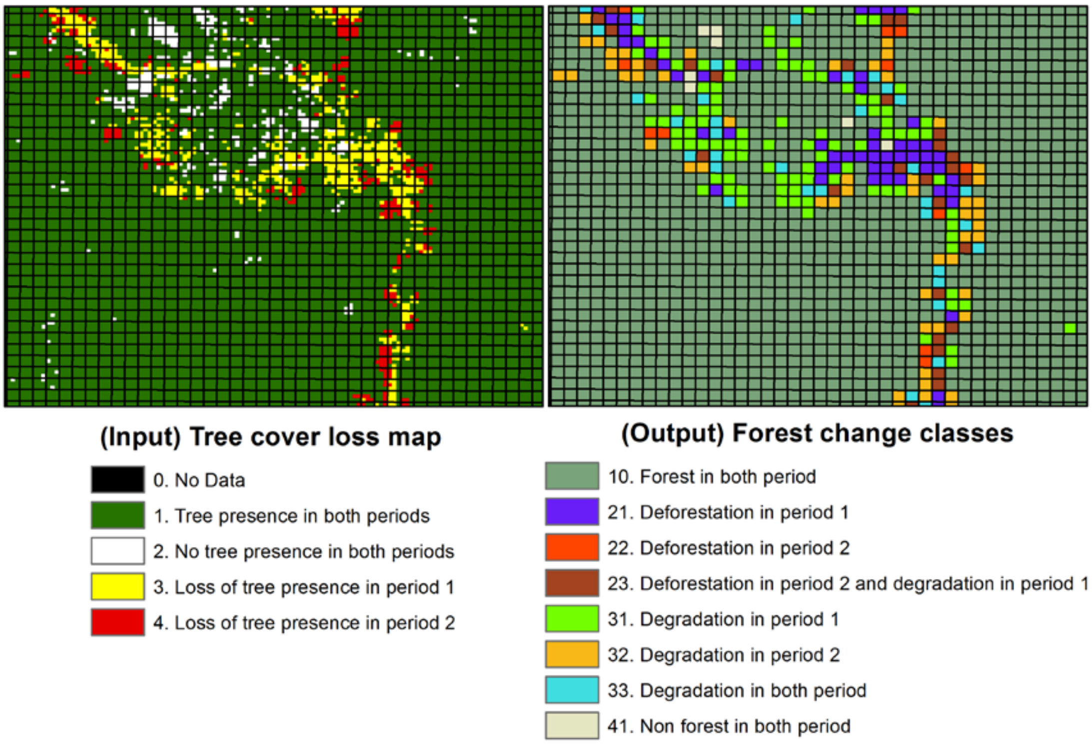


Figure 4: Examples of forest conversion classes for a 3x3 minimum forest unit and a 30% crown cover threshold. The left image shows the changes at the pixel level with the colour coding from Table 1. The right image shows the result at the minimum forest unit, with colour coding from Table 2.

Table 2 : Legend of the forest conversion classes according to the changes in the minimum forest unit

CLASS CODE	CLASS NAME	Description	Colour	rgb	hex
0	No data	More than 30% of ND in the unit area			
10	Forest in both period	No change found between period 1 and 2, remains forest		121,163,121	79a379
21	Deforestation p1	Deforestation was found during period 1 and no change in period 2		105,30,248	691ef8
24	Deforestation p1	Deforestation found in period 1 and some change still observed in period 2		105,30,248	691ef8
22	Deforestation p2	Deforestation was found during period 2		255,69,0	ff4500
23	Degradation p1 & Deforestation p2	Degradation found in period p1 and deforestation in period 2		163,67,32	a34320
31	Degradation p1	Degradation was found during period 1		115,255,0	73ff00
32	Degradation p2	Degradation was found during period 2		248,185,24	f8b918
33	Degradation, p1&p2	Degradation was found in both periods, 1 and 2		63,221,224	3fdde0
41	Non Forest in both period	No change found between period 1 and 2, remains non-forest		228,230,194	e4e6c2
42	Non Forest in both period	Status remains non-forest, though a change was found in p1.		228,230,194	e4e6c2
43	Non Forest in both period	Status remains non forest, though a change was found in p2		228,230,194	e4e6c2
44	Non Forest in both period	Status remains non forest, though a change was found in both p1 and p2		228,230,194	e4e6c2

3.2.2 Decision rules

At the end of the two time periods during which events of trees removal can have occurred, the status of each MFU is assessed. The MFU can be classified as:

- Never was a forest unit
- Was a forest unit before the two time periods, and is still a forest unit at the end;
- Was a forest unit before the two time periods, and is degraded at the end;
- Was a forest unit before the two time periods, and is deforested at the end (values below thresholds).

We make the distinction between the pixels classes, named as Tree (T) or Non-Tree (NT) and the MFU classes, defined as a forest unit in the sense of the IPCC definition.

To determine the forest change class of a MFU, decision rules use the pixel count of each class and the value of the tree cover threshold set by the user. For each MFU, the number of pixels belonging to the five classes (TT, NT, T-NT1, T-NT2 and ND, see notation in Table 1) of the tree cover loss map are counted. The sum of the five classes is equal to the number of pixels of a minimum forest unit – e.g. in the case of a 0.81 ha MFU size for Landsat, there would be nine pixels.

The number of pixels with tree presence at the beginning of the first period is counted by summing the three following classes:

T0 = T-T + T-NT1 + T-NT2

Decision rules classify each MFU according to the initial number of tree-presence pixel (T0) and whether the number of tree-presence pixel is modified during the two periods.

First, any MFU with a percentage of no-data (ND) pixels higher than the tree cover threshold is classified as no-data (ND) and not taken into account in the deforestation/degradation areas estimates.

Second, any MFU with an initial count of tree presence pixel (T0) below the tree cover threshold is classified as Non-Forest. Any loss of remaining tree pixels inside a MFU classified as Non-Forest is not taken into account in the estimates of emissions due to deforestation and forest degradation.

Then, any MFU with an initial count of tree presence pixel (T0) above or equal to the tree cover threshold belongs to a forest class. If no tree pixel loss was counted in the MFU, the unit is classified as Forest. If some tree pixels are lost in Period 1 or Period 2, the MFU is attributed a class of deforestation or forest degradation according to the remaining percentage of tree presence pixels (T-T). A MFU is considered as degraded if the remaining percentage of tree cover after the two periods is above the minimum percentage required by the forest definition; and deforested if the tree cover is lowered below this percentage.

The decision rules implemented in the module are presented in Figure 5 for a tree cover threshold of 30 %.

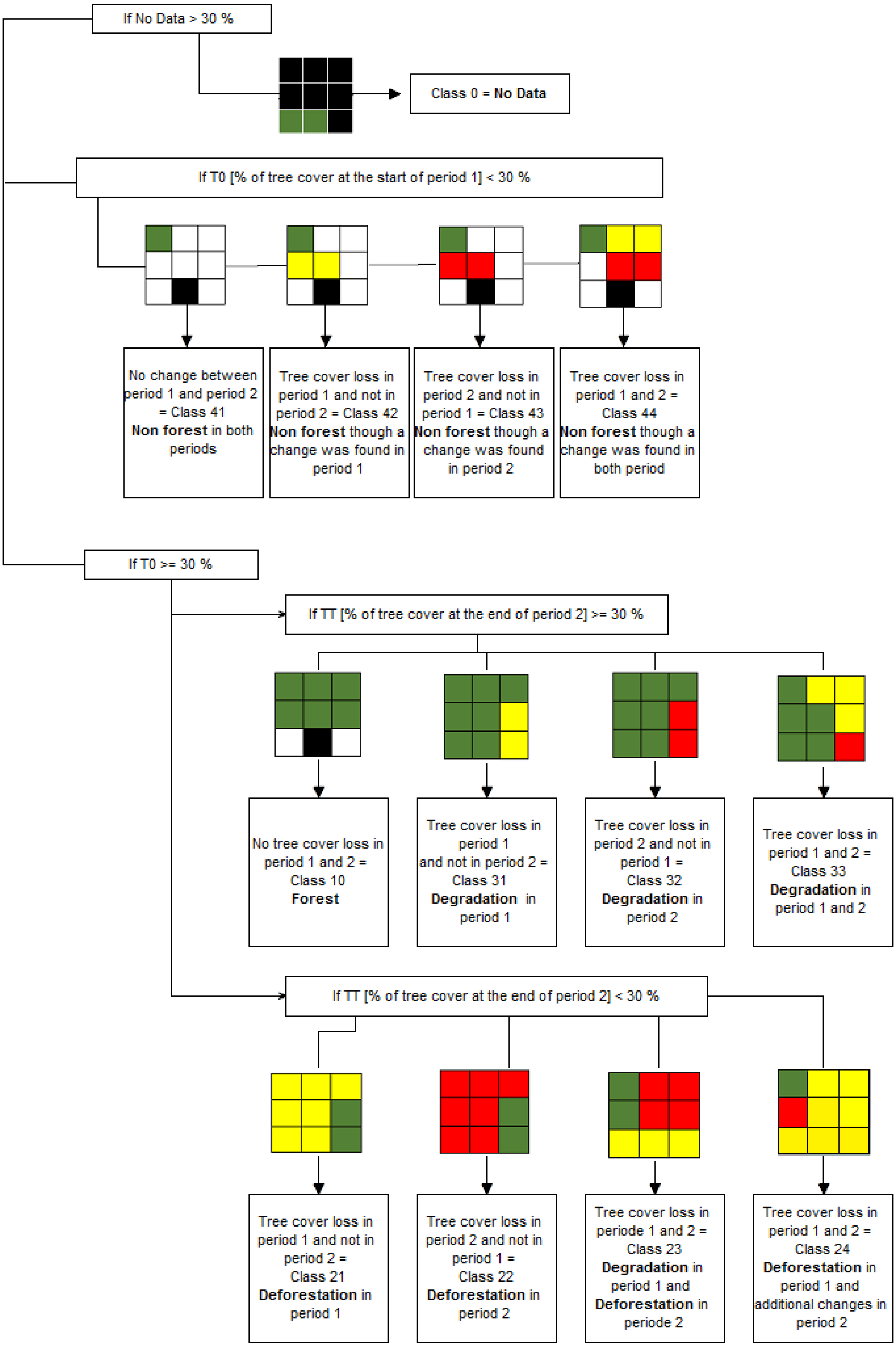


Figure 5: Decision rules for the minimum forest unit classes for a tree cover threshold of 30%.

3.2.3 Area of the MFU classes

The area of deforestation and degradation is reported at the scale of the whole MFU to indicate the overall trend of forest dynamics. However, this overestimates slightly degraded and deforested areas. The area estimates from option A and B are corrected for non-tree cover areas in the MFU and should be preferably used in reports.

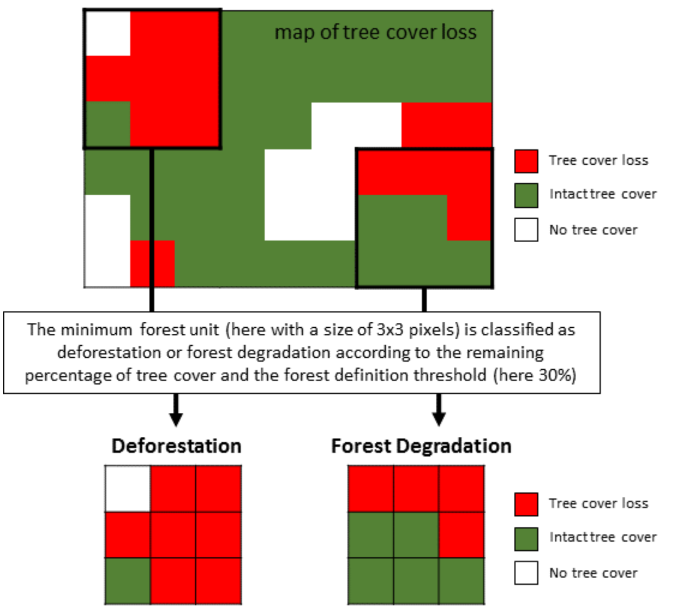
The full area of any MFU classified as class 21 or class 22 is summed and reported as deforestation (for period 1 and period 2, respectively) and class 31 or 32 as forest degradation (for period 1 and period 2, respectively). For MFUs encountering tree cover loss during the two periods, the area is reported as this; Class 23 as deforestation in period 2, Class 24 as deforestation in period 1 and Class 33 as degradation in a separate category.

Table 3: Area of deforestation and forest degradation at the scale of the Minimum Forest Unit are obtained by summing the deforested and degraded MFUs according to their class.

Contribution of each class to the estimates of areas per MFU			
Deforestation	Period 1	Class 21	Class 24
	Period 2	Class 22	Class 23
Forest degradation	Period 1	Class 31	
	Period 2	Class 32	
	Period 1 and 2	Class 33	

3.3 Estimates of areas of forest change and associated CO_2 emissions

Deforestation and degradation classification by MFU



Option A - MFU: the area deforested or degraded is equal to the area of tree cover in the UFM (tree cover + tree cover loss pixels)

Option B - Pixels: the area deforested or degraded is equal to the area of tree cover loss in the UFM (only pixels of tree cover loss)

Figure 6 : Option A and B for the accounting of areas of deforestation or degradation in a Minimum Forest Unit

The estimates of areas affected by deforestation and forest degradation and their associated CO_2 emissions are based on the classification of the MFU. As illustrated in Figure 6, only the MFUs with either a deforestation or a forest degradation class are considered for these estimates.

To cover different user needs, two options are available for reporting areas and CO_2 emissions due to deforestation and degradation. Option A considers the total tree cover of MFUs while option B accounts only for the specific pixels that removed tree cover. The choice between option A and B is left to the user. If the tree cover loss maps is prone to miss small size disturbances of tree cover, the user is advised to choose option A, as option B accounts for more details. The user can also choose one option for deforestation and another one for degradation.

In both options, a value of carbon stock is attributed to any pixel with tree-cover presence at the initial time. The carbon stock can be inserted either as a constant for the whole study area, or as a map. The initial carbon stock of each concerned MFU is determined by summing up the carbon content of any pixel with an initial tree cover (T0). The Emission factor is representing the quantity of carbon per MFU which is lost (and released to the atmosphere) during a conversion from forest to non-forest or from forest to degraded forest. This emission factor is defined according to the specificity of option A or option B.

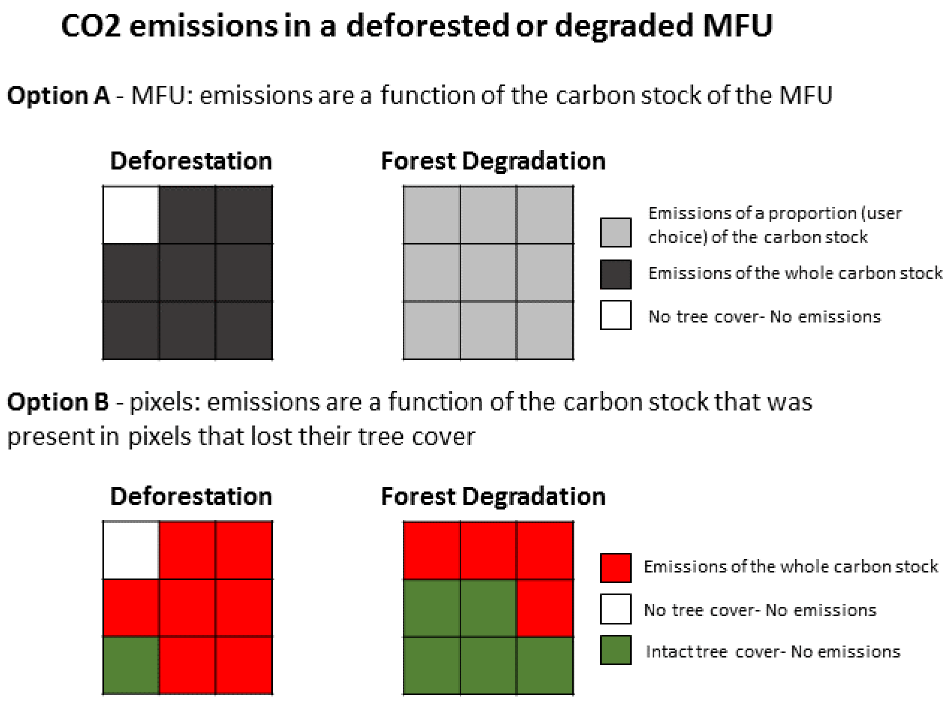


Figure 7 : Option A and B for the accounting of CO_2 emissions in Minimum Forest Unit classified as deforestation or degradation

3.3.1 Details of the computation for Option A

In option A, areas and CO_2 emissions are calculated according to the total tree cover area of the MFU (non-tree cover areas being removed from the MFU).

The area of the pixels indicated in Table 4 is summed-up for reporting the area of deforestation and degradation in the two periods. As illustrated in Figure 7, all pixels initially covered by trees are considered for calculating the emissions. For deforestation, the entire carbon content of the MFU is converted into CO_2 emissions. For forest degradation, only a proportion of the carbon content of the MFU is converted into CO_2 emissions. The proportion used is the value set by the user for the parameter "Proportion (%) of carbon stock emitted by degradation**"**. Table 5 summarized the contribution of each class to the deforestation and degradation emission estimates per period. The proportion indicated by the user for forest degradation is referred to as the "degradation factor – DF".

For the MFU with tree cover loss occurring over the two periods (class 24, class 23 and class 33), the areas and the emissions are reported as follows:

Class 23 – the area is reported as deforestation in period 2. The emissions are reported for degradation in period 1 and the remaining carbon stock is reported for deforestation in period 2;

Class 24 – the area and the emissions are reported as deforestation in period 1;

Class 33 – the area is reported as degradation in period 2 and the emissions are reported both in period 1 and in period 2.

Table 4: Estimations of the area of deforestation and forest degradation for option A. The area of pixels of tree cover and tree cover loss is taken into account into each MFU.

Contribution of each class to the estimates of areas for Option A			
Deforestation	Period 1	∑Area (Class 21 (T-T, T-NT1))	∑Area (Class 24 (T-T, T-NT1, T-NT2))
	Period 2	∑Area (Class 22 (T-T, T-NT2))	∑Area (Class 23 (T-T, T-NT1, T-NT2))
Forest degradation	Period 1	∑Area (Class 31 (T-T, T-NT1))	
	Period 2	∑Area (Class 32 (T-T, T-NT2))	∑Area (Class 33 (T-T, T-NT1, T-NT2))

Table 5: Estimations of the CO_2 emissions from deforestation and forest degradation for option A. The carbon stock of tree cover and tree cover loss pixels is taken into account into each MFU. For degraded MFU, only a proportion of the carbon stock (DF) is accounted for.

Contribution of each class to the estimates of CO_2 emissions for Option A				
Deforestation	Period 1	∑ CO_2 (Class 21 (T-T, T-NT1))	∑ CO_2 (Class 24 (T-T, T-NT1, T-NT2))	
	Period 2	∑ CO_2 (Class 22 (T-T, T-NT2))	∑ CO_2 (Class 23 [(T-T, T-NT1, T-NT2)*(1-DF)])	
Forest Degradation	Period 1	∑ CO_2 (Class 23 [(T-T, T-NT1, T-NT2) * DF])	∑ CO_2 (Class 31 [(T-T,T-NT1) *DF])	∑ CO_2 (Class 33 [(T-T,T-NT1)*DF])
	Period 2	∑ CO_2 (Class 32 [(T-T+T-NT2) * DF]	∑ CO_2 (Class 33 [(T-T, T-NT1, T-NT2)*(1-DF)*DF])	

3.3.2 Details of the computation for Option B

In option B, the areas and the emissions are calculated as the count of pixels of tree cover lost (T-NT1 and T-NT2 from the input map) within deforested or degraded MFUs. The specific accounting of T-NT1 and T-NT2 pixels is detailed in Table 6 for area estimates and in Table 7 for emissions estimates.

In case of tree cover loss occurring in both periods, the area and emissions are reported in the different classes as follows:

Class 23 – Pixels lost in period 1 (T-NT1) are accounted for areas and emissions from forest degradation in period 1. Pixels lost in period 2 (T-NT2) are accounted for areas and emissions from deforestation in period 2;

Class 24 - Pixels lost in period 1 (T-NT1) are accounted for areas and emissions from deforestation in period 1. No areas or emissions are accounted for any pixel lost in period 2 (T-NT2);

Class 33 - Pixels lost in period 1 (T-NT1) are accounted for areas and emissions from forest degradation in period 1. Pixels lost in period 2 (T-NT2) are accounted for areas and emissions from forest degradation in period 2.

Table 6: Estimations of the area of deforestation and forest degradation for option B. Only the area of tree cover loss pixels is taken into account in each MFU.

	Contribution of each class to the estimates of areas for Option B			
Deforestation	Period 1	∑Area (Class 21 (T-NT1))	∑Area (Class 24 (T-NT1)	
	Period 2	∑Area (Class 22 (T-NT2))	∑Area (Class 23 (T-NT2))	
Forest degradation	Period 1	∑Area (Class 31 (T-NT1))	∑Area (Class 23 (T-NT1))	∑Area (Class 33 (T-NT1))
	Period 2	∑Area (Class 32 (T-NT2))	∑Area (Class 33 (T-NT2))	

Table 7: Estimations of the CO_2 emissions from deforestation and forest degradation for option B. Only the carbon stock relative to tree cover loss pixels is taken into account into each MFU.

	Contribution of each class to the estimates of CO_2 emissions for Option B			
Deforestation	Period 1	∑ CO_2 (Class 21 (T-NT1))	∑ CO_2 (Class 24 (T-NT1)	
	Period 2	∑ CO_2 (Class 22 (T-NT2))	∑ CO_2 (Class 23 (T-NT2))	
Forest degradation	Period 1	∑ CO_2 (Class 31 (T-NT1))	∑ CO_2 (Class 23 (T-NT1))	∑ CO_2 (Class 33 (T-NT1))
	Period 2	∑ CO_2 (Class 32 (T-NT2))	∑ CO_2 (Class 33 (T-NT2))	

3.4 Outputs

3.4.1 Forest change classes image

A single band raster with the classes of the minimum forest unit is created with a colour map corresponding to the legend of Table 1. The spatial resolution of the raster is equal to the size of the MFU (the output pixel size matches the MFU width and height).

3.4.2 Report on the forest area change and associated emissions

The algorithm creates a text, in html format, and Microsoft ® Office Excel file, reporting for the areas lost and their corresponding emissions, either as degradation or deforestation, for the two periods of time. The text and Excel reports are produced in English and French.

The html file can be edited or copied into another document. An example is available below. The text report has two main sections; the first section reports details about the processing and the datasets used; the second section reports estimations of forest change and resulting emissions estimates for both option A and B.

In the Microsoft ® Office Excel file, the user can find the same figures together with additional details. It provides the number of forest units that have changed after the two periods, and is useful for indicating the overall forest dynamics. Second, whenever a landuse shapefile is used, the related information is available in the Microsoft ® Office Excel file under the option A and option B tabs. Third, a tab is dedicated to the reporting of the area of excluded areas, if any.

1. Reporting areas and emissions of deforestation and forest degradation

The reporting of areas affected by deforestation and forest degradation and their associated CO_2 emissions is based on the MFU classes. Only the MFUs classified as deforested or degraded are considered for the reporting. The area of deforested or degraded MFUs is available in the Excel version of the report.

Two options are available. Option A considers the total forest cover of the MFUs while option B uses only the pixels that are detected as tree cover loss in deforested or degraded MFUs. The choice between option A and B is left to the user, according the requirements of the study and of the quality of the tree cover loss data at his/her disposal. In case of tree cover loss maps that are prone to miss small size disturbances of tree cover, the user is advised to choose option A.

Area of forest at the start of the analysis

Total area of forest (MFUs area are adjusted for non-forest presence) at the start of the period 1 (YYYY): xxxx ha

OPTION A – Minimum Forest Unit

In option A, the areas and emissions are calculated according to the entire tree cover content of the MFU (the MFU area is adjusted for non-tree cover presence). For deforestation, the entire carbon content of the MFUs is converted in CO_2 emissions. For forest degradation, a proportion of the carbon content of the MFUs is converted into CO_2 emissions. The proportion is indicated by the user as the “Proportion (%) of carbon stock emitted by degradation”. For option A, a proportion of: 30.0% of the MFU carbon stock is used for calculating the forest degradation emission factors.

	Total (ha)	Total (tEq CO_2)	Annual rate (ha/year)	Annual rate (tEq CO_2/year)
Period YYYY-YYYY				
Deforestation	xxxx	xxxx	xx	xx
Forest degradation	xxxx	xxxx	xx	xx
Period YYYY-YYYY				
Deforestation	xxxx	xxxx	xx	xx
Forest degradation	xxxx	xxxx	xx	xx
Period YYYY-YYYY				
Deforestation	xxxx	xxxx	xx	xx
Forest degradation	xxxx	xxxx	xx	xx

Option B – Pixels of tree cover loss

In option B, the areas and the emissions are calculated according to count of tree cover pixels loss in deforested or degraded MFUs. The emissions are calculated in the same way for deforestation and degradation. In both case, only the carbon content present in the pixels of tree cover loss is converted in CO_2 emissions.

	Total (ha)	Total (tEq CO_2)	Annual rate (ha/year)	Annual rate (tEq CO_2/year)
Period YYYY-YYYY				
Deforestation	xxxx	xxxx	xx	xx
Forest degradation	xxxx	xxxx	xx	xx
Period YYYY-YYYY				
Deforestation	xxxx	xxxx	xx	xx
Forest degradation	xxxx	xxxx	xx	xx
Period YYYY-YYYY				
Deforestation	xxxx	xxxx	xx	xx

Forest degradation	xxxx	xxxx	xx	xx

2. Exceptions: area excluded from the analysis

The following table indicates the areas chosen by the user to be excluded from the analysis above. The user has to indicate the period (1 or 2) to which each exception refers to. The total biomass in tC of the area is reported, not its value in equivalent CO_2.

Exception code	Area (ha)	Carbon stock (tC/ha)
x	xxxx ha	xxxx tC/ha

3. Forest changes per landuse strata

The area and emissions of deforestation and forest degradation disaggregated by land use classes is found in the Excel file.

4 The module in Impact Tool

The CarbEF module is integrated into the JRC's open source software package "IMPACT tool". The software package is available from:

Web: http://forobs.jrc.ec.europa.eu/products/software

Wiki: https://webgate.ec.europa.eu/fpfis/mwikis/impacttoolbox

The module is located under the "degradation" panel and is called CarbEF "Reporting on forest carbon emission (degradation and deforestation)" (Figure 8). Click on the CarbEF icon to open CarbEF interface (Figure 9).

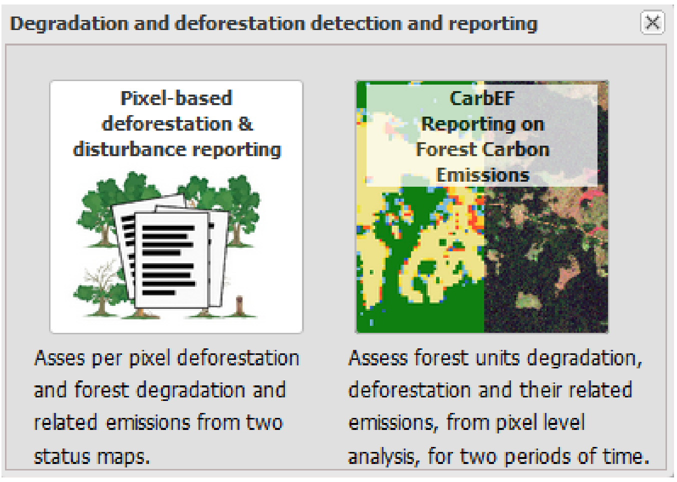


Figure 8 : The degradation and deforestation detection and reporting panel in IMPACT

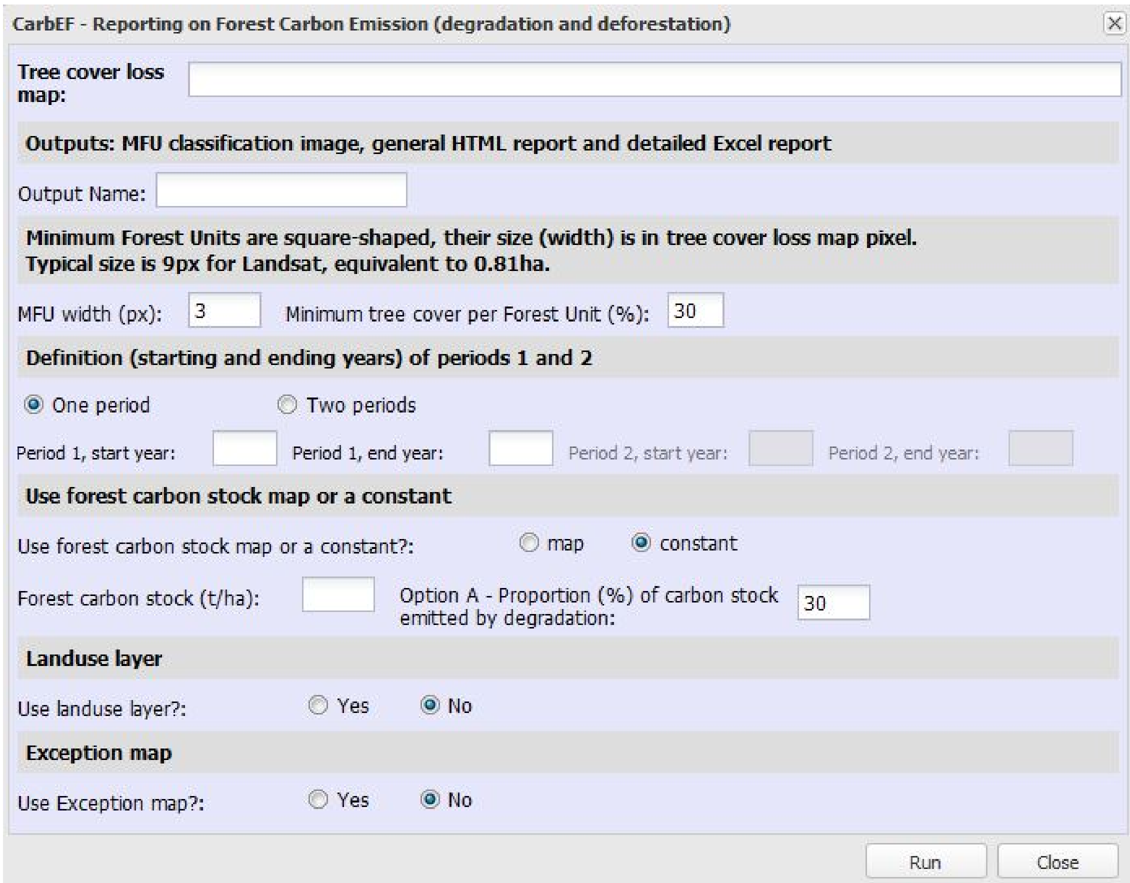


Figure 9 : CarbEF module user interface

4.1 Inputs

Tree cover loss map

The master image of the CarbEF module is the tree cover loss map chosen for the analysis. The input image must be a raster with four (five) classes illustrating pixel that lost tree cover in one (two) periods). An example of a colour map is shown in Table 1.

Be aware that the software implicitly links period 1 to code 3 in the activity map, and period 2 to code 4. Be attentive to assign correctly code 3 or code 4 for the occurrence of the tree cover loss events.

IMPACTools has a range of tools allowing to interactively edit the tree cover loss map and keep what is relevant.

Input Variables

1) Output Name

Choose the prefix for the output products name

2) MFU width (in pixels)

Choose the minimum forest unit width. The unit is in pixel. Choose it according to the spatial resolution of the input map and the minimum ground area of the forest definition. A minimum forest unit width of minimum 3 pixels is recommended (each pixel represents 11%).

The output image has the spatial resolution of the Minimum Forest Unit (*i.e.* 1 pixel of the output image represent one MFU). The MFU grid upper left corner coincides with the upper left corner of the input map.

3) Minimum tree cover per minimum forest unit (%)

Choose a value (in percentage) for the tree cover per minimum forest unit. This corresponds to the crown tree cover of the forest definition. It is set by default to 30 % and it is highly recommended not to go below 30 % (3 pixels = 33%) for a minimum forest unit of 3 x 3 pixels.

4) Definition of periods 1 and 2

By default, CarbEF is running for 1 period. If the user wants to consider 2 periods, he has to tick the “two periods” box. The two periods cannot overlap.

In the case of 1 period, it will consider only the definition of period 1, which means that the input map can’t have code 4 values (tree cover loss occurring in period 2). When using only a single period, CarbEF will show an error message if a pixel with value 4 is found in the activity map: please correct the tree cover loss map accordingly.

Indicate the start and end years of the 1 or 2 periods of change to be processed in the module. The years must be on 4 digits, such as 1985, 1996, 2001, 2017.

Each period starts at the beginning of a year and end at the end of a year. So start=2010 end =2011, means that the period spans from January 2010 to December 2011. To define a period of 1 year, say 2016, use start=2016, end=2016.

The starting and ending years are used to compute the duration of each period, and therefore the annual emission rates.

5) Carbon stock map or factor

For the carbon stock, the user can choose if they want to use a constant value or a map. In the case of a constant value enter it in the box “Forest carbon stock (tC/ha)”. Choose a value corresponding to the forest type present in the study area. In the case of a map, tick the map box. In both cases, the unit is in tons carbon per hectare (tC/ha).

The 30% default value of "Option A- Proportion (%) of carbon stock emitted by degradation" can be modified to a value between 0 and 100.

6) Land use (optional)

To use a shapefile indicating the different landuse, tick the yes option after "use Landuse layer", tick the shapefile in the "Disaggregation shapefile" window appearing in the optional layer panel and indicate the field of the shapefile containing the information about the landuse classes in the drop down list of "select a field".

7) Exceptions (optional)

The concept of "exceptions" let the user remove some areas from the main emissions calculations. For this, the user must prepare a map (the so-called exception map), with the following rules for the pixel values:

- 0: no exception, counting pixels, areas and emissions as usual
- any other value: define a class of exception.

Pixels of the activity map found with a non-zero code have their areas summed up. The final report will list all exception codes, and the associated total area of pixels associated with this code.

4.2 Outputs

An image of the classification of the MFU is generated together with an html and Microsoft ® Office Excel report presenting the estimations of forest areas changes and resulting carbon emissions for Option A and Option B.

Forest change classes image

A single band raster with the classes of the minimum forest unit with a colour map corresponding to the legend in Table 1, with the name:

[output name] _class.tif

Reports on the forest area change and resulting emissions

The reports are created as an html and Microsoft ® Office Excel file. To display the files: once processing is done, click on "logs Monitor", then open the log file of your processing (click on "show info"), and then click on the file blue link (click on "view report result"): the report is displayed in a new tab.

You can either copy the whole report and paste it in a text processor (such as Microsoft ® Office Word) or get a copy of the file: you can find your file in Impact tool data directory, under DATA/USER_data. If you entered "example" for the output_name, you should see a file named example_FR.html, example_EN.html, example_FR.xlsx, example_EN.xlsx. You can copy those files and edit them.

5 External resources

5.1 Construction of a forest emission reference level

The literature concerning the construction of a forest emission reference level is abundant; here are some key documents on the topic.

[1] UN-REDD Programme, Technical considerations for Forest Reference Emission Level and / or Forest Reference Level construction for REDD+ under the UNFCCC. 2015.

[2] M. Sandker, D. Lee, P. Crete, and M. Sanz-Sanchez, “Emerging approaches to Forest Reference Emission Levels and/or Forest Reference Levels for REDD+,” p. 43, 2014.

[3] S.M. Walker, E. Swails, S. Petrova, K. Goslee, A. Grais, F. Casarim and S. Brown , 2013, “Technical Guidance on Development of a REDD + Reference level Technical Guidance on Development of a REDD + Reference Level May 2013 Version”, Winrock International, Ecosystem Services Unit

5.2 Using existing remote sensing based products

The module is processing tree cover loss maps that are produced beforehand. Global maps derived from satellite data such as the Global Forest Change map can be used to produce a tree cover loss map suitable for the module.

Here is a script to be run in the cloud computation platform Google Earth Engine (GEE) to reclassify it into a suitable tree cover loss map.

GEE script for Global Forest change product (a private account in GEE is required):

For a single period:

https://code.earthengine.google.com/71bfe41ec938ca9287883e3d05480b19

For two periods:

https://code.earthengine.google.com/66490c593c79e2a4692d4b3f8f1330aa

5.3 Suitability of LANDSAT for two periods comparison

When using LANDSAT data to compare two periods, e.g. reference and commitment periods set respectively at 2000-2012 and after 2012 as often requested in FREL, the bias in the detection of forest change according to the number of acquisition of Landsat images has to be considered.

Before the change of acquisition strategy of Landsat 7 and the arrival of Landsat 8, the number of valid observation over Central Africa are reduced, see the graphs below (Vancutsem et al., in preparation).

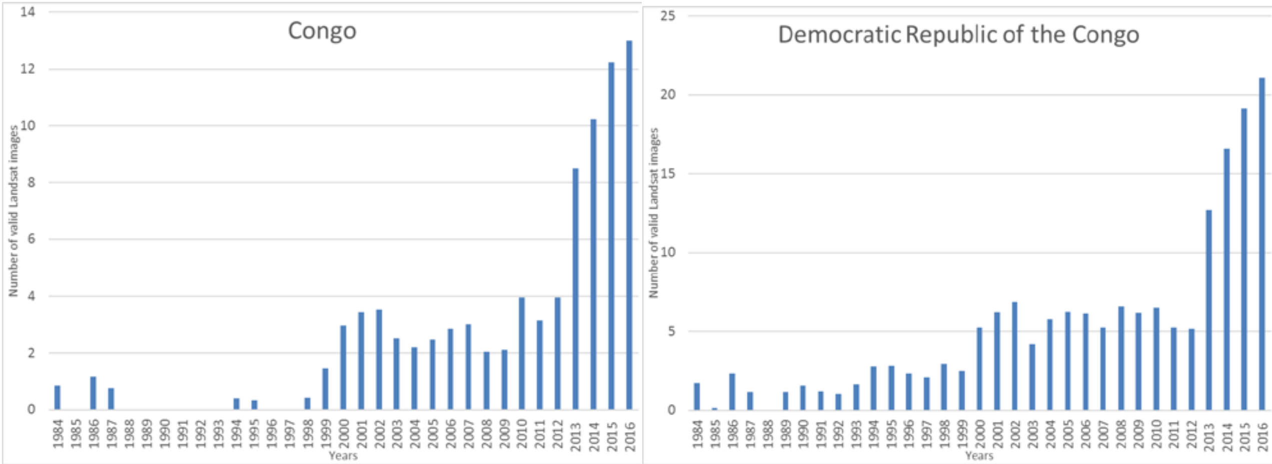


Figure 10 : Landsat valid images available over the entire country - Republic of Congo and the Democratic Republic of Congo - for the period 1984-2016 (Vancutsem et al. (in preparation))

6 Conclusion and perspectives

A methodology and a software have been developed for estimating areas and carbon emissions resulting from forest degradation and deforestation, in one or two periods of time. The software relies on two mandatory inputs: a map of tree cover loss and a map or a value of the carbon stock for the study area. This allows the user to use the best dataset available for their study area and to update the analysis anytime a better product is released. The user expertise is concentrated on the selection of the datasets and the choice of the parameters to run the software.

The approach assumes that the forest status (unchanged, degraded or deforested) can be assessed by considering tree cover loss events inside minimum forest units (MFU). The driving force for this approach came from the requests from national forest agencies to perform an analysis taking into account the official definition of forest. Two parameters of the definition are considered in the methodology, the minimum area and the crown cover threshold.

The MFU size is defined to be as close as possible to the minimum area threshold of the definition. The tree cover loss map is analysed inside a grid of MFU. The MFUs are considered as a forest class if their initial tree cover equals or exceeds the tree crown cover percentage threshold. The distinction between deforestation and forest degradation comes from the tree cover percentage remaining at the end of the change period. Deforestation occurs when the tree cover falls below the threshold and degradation when the tree cover remains above the set threshold.

Estimates of areas and CO_2 emissions associated to deforestation and degradation are reported for two computation options (named A and B). The option A takes into account the total content of tree cover of the forest unit in the estimations. Option B only considers pixels that are mapped as a tree cover loss in the input map. The user chooses the option to consider according to the requirements of its study.

The approach focus on regional to national assessment of the deforestation and degradation processes and their contribution to the total emissions. For this reason, the software can break down the estimates for different areas, in particular to identify contributions from the different kind of anthropogenic activities (concessions, charcoal production, etc.). An option to exclude some area of large disturbances (e.g. wind, fire or floods) that are not deforestation adds some flexibility to the use of the software.

However, this is a first release of the software, mainly designed for capacity building in Central Africa and reporting of deforestation and forest degradation in dense moist tropical forest. Future development will investigate the possibility to take into account the regrowth information.

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